DEPARTMENT OF COMMERCE AND LABOR
BUREAU OF STANDARDS
S. W. STRATTON . . Director

THE NATIONAL BUREAU OF STANDARDS

WASHINGTON
GOVERNMENT PRINTING OFFICE
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THE NATIONAL BUREAU OF STANDARDS.

INTRODUCTION.

In 1901 the National Bureau of Standards was established by Congress, with broad functions, consistent with the modern view of standards and standard measurements. In 10 years the bureau has grown to occupy an important place in the Government, having 286 employees, four laboratory buildings in Washington, and branch laboratories in Pittsburgh and Northampton, Pa., and in Charleston, S. C. The main laboratories are located in the northwestern suburbs of Washington at an elevation of 350 feet above the Potomac River, on a natural hill site of about 8 acres—a locality admirably suited to its work. A fifth building is under construction for the electrical work of the bureau. As rapidly as consistent with its standard of work the bureau has taken up the following functions as prescribed in its organic act:

(1) The custody of the standards, which involves their care and preservation and also the intercomparisons and researches necessary to maintain the constancy of such standards as are liable to change.

(2) The comparisons of standards for States, municipalities, institutions, and the general public—comprising standards used in commerce, manufacturing, and science, assuring to the public accuracy at its source—in the factory and the works laboratory.

(3) The construction of standards as required by scientific or technical progress. New standards are constructed at the bureau upon the basis of the best available data, in some cases upon researches at the bureau and sometimes by international agreement.

(4) Standardization of measuring apparatus for manufacturers as a test of their output, or for the user that he may verify instruments or materials independently.

(5) Technical research upon problems connected with standards, problems arising constantly in all lines of testing and stardardization. Such research facilitates scientific and technical progress, since by refined measurements alone are many of these advances made possible.

(6) Determination of physical constants, the measured data relating to materials and energy which underlie scientific and tech-

nical work. In such work direct reference to the standards is highly desirable.

(7) Determination of the properties of materials for general use in technology and trade. This work is based upon the modern view that quality depends upon definite measurable properties, and it therefore requires access to standard measuring apparatus and facilities for all kinds of measurements.

Weights and measures were once restricted to length, area, volume, and weight. Within recent years, however, since power, electric current, heat, light, irrigation, refrigeration, and services of other kinds have entered the world's markets as commodities for production and sale, the scope of weights and measures has broadened to include such measures as those of velocity, pressure, energy, electricity, temperature, and illumination. The importance of correct standards and uniformity of measures is readily appreciated. Almost every industry has its units, its particular methods of measurement, and its special measuring instruments. These instruments are designed for every particular need, and their variety is evidence of the high state of the art of measurement and its importance in industrial and scientific work. Such instruments have so multiplied and the demand has grown so rapidly that the manufacture of weights, measures, and measuring instruments now forms in itself a whole group of industries. While the testing of standards and instruments is an important part of the bureau's work, not less important is the research conducted to improve standards and methods of measurement. Hence it is necessary to maintain a force of men and an equipment for doing scientific work of the highest grade. The bureau, as a court of highest appeal in matters pertaining to measurement, must possess standards as perfect as possible. Its methods and instruments must be the best available, its laboratory facilities complete, and, finally, men of good training and experience must be in charge of each line of work.

The standards of the bureau are made available for the service of the public in several ways. First, the States of the Union have been furnished by the Federal Government with sets of the metric and customary standards, which from time to time may be reverified. Standardizing facilities are thus afforded for local inspection of trade measures. Secondly, tests are made of manufacturers' standards to enable them to maintain a high standard of accuracy in their output. Finally, the general public submits to the bureau standards and measuring instruments for direct test at nominal fees. The willing cooperation of State sealers and of manufacturers has resulted in a steady, and in some cases rapid, improvement in industrial standards and products. In each line of standardization the cooperation of the manufacturers and technical experts was first secured. Large errors were often found in the products submitted for

test or bought in the open market. An investigation of the standards used by manufacturers showed that these were frequently in error by amounts that could by no means be neglected. In many such cases the bureau loaned or sold standards carefully verified by the bureau, and the ready cooperation of the manufacturers greatly facilitated the work. The steady improvement in the measuring instruments submitted for test is sufficient evidence of the effectiveness of this work. Its importance to industry itself and to the general public can hardly be overestimated. Directly or indirectly through the State and local inspectors and the manufacturers the bureau is rapidly bringing about a realization of the need of more perfect standards and providing means by which they may be applied to all the varied needs of industry, science, and trade.

The bureau is, to a certain extent, a clearing house for technical information. It is constantly consulted by State and municipal officials, and technical bodies such as public-service corporations and commissions. The bureau cooperates to the fullest extent possible with all movements tending to improve conditions in which standards of quality or standards of measurement are involved. In this way the bureau is influencing in a far-reaching way the establishment of standardized conditions in the distribution of public services as well as promoting accuracy in commercial relations.

LENGTH.

To meet the modern demands for uniformity and precision, all length standards are based upon the international meter, which is defined as the distance, at the temperature of melting ice, between two fine lines ruled on a bar of platinum-iridium preserved at the International Bureau of Weights and Measures near Paris, France. Accurate copies or prototypes have been made, and after numerous comparisons with the international meter and among themselves they have been distributed among the Governments of the world. The bureau is in possession of national prototype No. 27. From this standard are derived all other standards of length used in the United States, with their subdivisions and multiples, including the yard, using the relation between the yard and the meter (1 meter= 39.37 inches) fixed by the act of 1866.

Length measures are standardized under definite conditions of temperature and manner of support. The tests include gauges, bars, rules, tapes, level rods, and a great variety of special apparatus. The researches in progress relate to the construction and maintenance of standards of different types and their proper use and care. Particular attention is being given to the measurement of the expansion of materials at high temperatures under conditions not

covered by ordinary investigations but of prime importance in modern engineering.

In most lines of construction and engineering the need of an accurate standard of length is evident. The surveyor or engineer requires steel tapes to measure distances and it is necessary that the true length be known in terms of a universal standard of reference. The unit of length must have the same value everywhere to secure perfect construction and interchangeability of parts in machinery. This can only be done by having accurate and universal standards.

MASS.

To secure reliability and permanence the standard of mass (commonly called weight) is a certain cylinder of platinum-iridium known as the international kilogram, also preserved at the International Bureau of Weights and Measures. From this kilogram copies have been made, having the same mass, material, and form, and after careful comparisons to establish their value they have been distributed among the various nations of the world. The bureau is in possession of two such copies, Nos. 4 and 20. From the kilogram all other units of mass, such as the pound avoirdupois, pound Troy, etc., are now derived in the United States.

Weights are classified according to their design and use, and are tested in conformity with the classification. The weights tested range from those used by a state or city sealer in testing commercial weights and measures to those used by the scientist in most precise and exacting work.

Researches made from time to time cover a wide field affecting directly and indirectly the maintenance, preservation, and proper use of standards of mass. Millions of dollars are annually involved in the tests and determinations, made by engineers and chemists, in which weights of high accuracy must be used.

VOLUME.

Volume measurements, such as the gallon and bushel, are defined as a certain number of cubic inches. In the metric system the volume occupied by a kilogram of water at maximum density is the liter.

Tests of such volumetric apparatus are made by determining the amount of distilled water at a certain temperature that is contained or delivered by the vessel. The tests range from half-bushel measures to cubic-centimeter pipettes. Each year many thousand glass measuring instruments, including flasks, pipettes, burettes, cylinders, and vessels of all kinds are tested. The test of cubic-foot standards, used in standardizing gas and water meter provers, is of growing importance.

Investigations covering questions of detail and design are important when precise volumetric measurements are involved. A container made of 1-liter capacity will not deliver a full liter of a liquid, and it is necessary to have precise data on this difference. Precise volumetric apparatus is, therefore, marked "to contain" or "to deliver."

The glassware tested is of importance to chemists. The chemist in making analyses, whether of the constitution of rubber or steel or of a sample of food, needs accurately calibrated glassware. With the advance in modern requirements the testing of capacities is steadily assuming greater importance.

DENSITY.

In a large class of materials used in commerce, science, and the arts, it is important to determine the density or the weight of a unit volume of a substance. In the case of liquids this can be accomplished with a high degree of accuracy by hydrometers. Hydrometers are usually glass bulbs with a stem which when placed in a liquid sinks to a certain level, indicating the density by graduations on the stem.

In order to use hydrometers with confidence it is necessary that they be carefully tested. The bureau tests annually hundreds of hydrometers, largely for the use of the revenue service of the Government. Besides testing hydrometers, the bureau is called upon to make careful determinations of the densities of materials, in both solid and liquid forms, of special interest and importance to revenue, commerce, engineering, and science. The bureau is also frequently called upon to ascertain the expansion of various liquids upon increase of temperature.

The bureau has just completed an elaborate series of investigations giving probably the best-known values for densities of mixtures of alcohol and water. This has a vital bearing on the work of the internal-revenue branch of the Government, which collects the tax on malt and spirituous liquors.

Hydrometers are used to a very great extent in the petroleum industry and by manufacturing chemists and in tests and classifications of various kinds. The importance of testing hydrometers is better appreciated after knowing that the Government collects an annual internal revenue of $150,000,000 on values obtained by means of hydrometers.

TRADE WEIGHTS AND MEASURES.

The Bureau of Standards is by law charged with the preservation and care of the standard weights and measures of the National Government, and soon after the establishment of the bureau, in 1901, it

began to receive inquiries from State and private institutions, manufacturers, and from the general public for information, advice, and assistance concerning weights and measures. The inquiries from the beginning showed the great variation existing in the different States and the lack of standardization in many common measures of quantity, such as the barrel of potatoes or apples and of boxes, crates, baskets of various produce, the bushel of various grains, etc. Enormous losses to the public naturally result from such a condition of affairs, and dishonest dealers take advantage of these conditions to their own profit.

Recognizing the benefits which would come from unifying the weights and measures and methods in use throughout the country, Congress made an appropriation two years ago to enable the bureau to make an investigation of the actual conditions throughout the States. With two inspectors engaged in this work, 170 cities in 46 States have been inspected. More than 8,700 scales and 18,000 pieces of other weights and measures apparatus have been inspected. The investigation showed that a large number of fraudulent or defective weights and measures are in daily use.

Through the information thus obtained the bureau has been able to point out existing evils and to aid States and cities in drafting and perfecting their ordinances on this subject. The results have been gratifying. During the past year 12 States have enacted laws which will result in State-wide supervision and inspection of weights and measures. Seventeen other States have enacted legislation of a minor character—but nevertheless important—and 8 States considered legislation which failed of passage.

It is the hope of the bureau that by directing and encouraging cooperation among the States uniformity will be secured, and that the enormous losses now sustained by the purchasing public, whether through dishonesty or carelessness, will be reduced to a minimum.

BAROMETRY.

The needs of explorers and surveyors, and the advent of the modern flying machine, have emphasized the need of an accurate and ready means of measuring elevations. This has directed attention to the limitations and imperfections of the aneroid barometer, used for this purpose. The bureau is investigating the behavior of such barometers of different designs under various conditions, to locate the faults, with the object of improving the instrument. Standard specifications and tests for these instruments are being developed which as far as practicable will include all the factors affecting the operation, such as mechanical accuracy, elastic lag, temperature compensation, permanency, etc. Mercurial barometers of the ordinary laboratory type and those used for meteorological purposes are also tested by the bureau.

TIME.

The bureau is preparing to take up the testing for the public of the better grade of watches. They will be run for several weeks in the various positions for which they are adjusted in a room heated to summer temperatures and again cooled to nearly freezing. Any watch passing the required tests will be granted a certificate or report of its performance. Standards of accuracy will be established which will indicate the degree of accuracy which may be expected from watches of different grades and enable a purchaser to secure a certified watch if he so desires. Chronometers and clocks, also, will be similarly tested. The bureau recently completed an extended investigation of master and secondary clocks for the Treasury Department, to determine their suitability for installation in public buildings of the Government.

ELECTRICITY.

The accurate measurement of the various electrical quantities occurring in practice is of great commercial and technical importance, as well as of scientific interest. The bureau is responsible for the maintenance of the units in terms of which such measurements are made, and by cooperation with other national laboratories international uniformity has been secured. In addition to this work, improved standards and measuring apparatus have been developed, and in some cases the accuracy of measurement greatly increased. The testing and certification of electric instruments for all who employ them in their work is also an important function of the bureau.

INTERNATIONAL ELECTRICAL UNITS.

The units to which electrical measurements are referred were adopted by the London International Electrical Conference of 1908. The fundamental units are the following: (1) The international ohm, defined in terms of the resistance, at the temperature of melting ice, of a uniform column of mercury of specified dimensions; and (2) the international ampere, the unit of current, defined by the rate at which silver is deposited by an electric current in the silver voltameter.

The completion of specifications for the voltameter, in order to assure the highest accuracy and the adoption of a value for the Weston normal cell used in practice to define the international volt, was left to an international committee, under the auspices of which cooperative work was carried out at the bureau in the spring of 1910 by representatives of the national laboratories of England, Germany, France, and America.

The bureau has for a number of years been engaged in investigations having for their object the concrete realization of the fundamental electrical units to the highest degree of precision.

ELECTRIC RESISTANCE.

Four copies of the International Ohm have been constructed. This involved a study of variations in cross-section of the mercury column due to minute irregularities in the capillary tube containing the mercury, the accurate determination of the length of the tube, its mercury content, and the precision comparisons with wire-resistance coils employed as secondary standards for routine testing work. The resistance units represented by the different tubes differ from the mean of all by only 5 parts in 1,000,000, and the mean is in agreement with the units employed in Germany and England to a very few parts in 100,000.

ELECTRIC CURRENT.

The investigation of the voltameter has shown that the previously recognized type was subject to large errors due to the contamination of the electrolyte by the filter paper employed even when the highest grade paper was used. When the latter is replaced by a porous porcelain pot the results of current measurement were found to agree to a few parts in 100,000, and practically the same result is obtained in another type in which neither filter paper nor porous pot is employed. The investigation brought to light the considerable influence on the result of exceedingly small traces of certain impurities. The experience gained will be utilized in drawing up the official specifications for the use of the voltameter.

ELECTROMOTIVE FORCE.

A special study has been made of the method of preparation and purification of the materials employed in the construction of the Weston normal cell, which is in practice used to define the unit of electromotive force. The standard cell is reproducible to a few parts in 100,000 if the cells are set up in accordance with specifications based on the result of recent investigations.

ABSOLUTE ELECTRICAL UNITS.

From the fundamental electrical units, the ohm and ampere (or in practice the ohm and volt), all the remaining units for the measurement of electrical quantities are derivable.

There is, however, another system of electrical units based upon the units of length, mass, and time, and therefore independent of the properties of materials. These units are called absolute units, and upon them are based the international units mentioned above. On account of the scientific and theoretical importance of the subject the bureau has been engaged in the development of a current balance, by means of which currents can be measured with great accuracy in absolute units. This involves the calculation of the precise attraction or repulsion of a moving coil by a pair of fixed coils, all the

coils carrying the current to be measured. The movable coil is attached to one arm of a balance and the force of attraction is measured by weighing.

The results obtained with the current balance indicate that currents can be measured in absolute units to within a few parts in 100,000 and that the absolute and international ampere do not differ by more than 5 parts in 100,000. The apparatus for the determination of resistance in absolute measure has been constructed and the measurements will shortly be carried out.

CONDUCTIVITY.

The bureau recently made an investigation of the conductivity and temperature coefficient of copper used in such enormous quantities by the electrical industries. By such measurements the degree of purity of a copper sample may be ascertained, certain impurities exerting an influence hundreds of times greater than that corresponding to the percentage in which they are present. The results obtained were made the basis of the new copper wire tables adopted by the American Institute of Electrical Engineers.

CAPACITY AND INDUCTANCE.

In alternating current work and in dealing with intermittent or varying currents the capacity and inductance of a circuit are always of importance. This applies to alternating current transmission of power, to telegraphy, submarine cabling, telephony, and radiotelegraphy. Indeed, in a radiotelegraphic circuit where the changes in the current are very rapid, the capacity and inductance are the most important constants of the circuit.

The standards of capacity are mica and air condensers, the mica condensers being used for values of the capacity greater than 0.01 microfarad, and the air condensers for lower values. Condensers to be tested are compared with these standards by the use either of alternating or direct current, according to the purpose for which the condensers are to be used. Frequencies of alternating current from 25 to 3,000 cycles are available for this use.

The standards of inductance are coils of copper wire wound on marble spools, which are nonmagnetic and very permanent. Standards are also in the possession of the bureau, which are so wound that their inductance can be computed from their dimensions.

ELECTRIC INSTRUMENTS.

Another branch of electrical work is the testing of the electric measuring instruments largely used by electrical engineers. This occupies a mid-position between the work of an engineering laboratory and that of a scientific one. An important part of the work is the thorough investigation of instrument types.

Among the instruments tested and certified by the bureau are resistance standards, precision rheostats, wheatstone bridges, potentiometers and other resistance apparatus, and standard cells, all of which are employed in scientific work and in the more accurate measurement of the testing laboratories of the manufacturers of electrical apparatus, and of the light and power companies.

The instruments most frequently tested are ammeters, voltmeters, wattmeters, watt-hour meters, and current and potential transformers, although many other types are often tested. The reference standards most used in this work are standard cells and standard resistances, and the potentiometer, which is the most accurate device for the measurement of voltage. A small testing room has been installed, the temperature of which may be maintained at any desired value between considerable limits, so that the effect of temperature upon any instrument may be determined.

The watt-hour meter is the instrument of the greatest direct commercial importance since it is almost universally used wherever electric power is sold. Instrument transformers are used as auxiliary apparatus in the measurement of very large amounts of power in alternating-current circuits.

The accuracy required in all such measurements is steadily increasing, and consequently instruments are being developed to increase both the range and the accuracy of such measurements.

MAGNETISM.

Because of its magnetic properties iron enters to a great extent into the construction of electrical machinery and apparatus. Its value consists largely in its intense magnetization when it is subjected to moderate magnetizing forces. This property of having a high magnetic permeability makes it useful for field magnets and armatures in a great variety of machines and apparatus and for alternating-current transformers. A second characteristic is the retention of a certain amount of magnetization after the magnetizing force has been removed. This property is valuable in steel to be used for permanent magnets, such as are used in telephone receivers, magnetos, and electric measuring instruments.

The measurements of the above characteristics are made with direct current, and are known as normal-induction and hysteresis measurements.

Besides the above there is another characteristic of iron and steel which is of great importance for material to be used in armatures, transformers, and all devices in which there is a repeated reversal of magnetization. This is the energy loss that inevitably results when iron or steel has its magnetization reversed, and is known as

core loss. It is very desirable that this loss be kept as low as possible. It has been estimated that in the United States alone the energy dissipated in core losses amounts to millions of dollars annually. Recently great improvements in material have been made, and the best transformer steels of to-day show only half the loss of the best material of a decade ago.

Investigations are in progress to show the relation between the magnetic properties and the chemical composition and heat treatment of various steels.

Other materials besides iron and iron alloys are of importance from a magnetic standpoint. For certain purposes it is desirable to have as nearly nonmagnetic materials as possible. Some alloys containing a considerable percentage of iron are practically nonmagnetic, while certain alloys of nonmagnetic metals are magnetic. An investigation of such slightly magnetic materials is, therefore, sometimes of importance.

PHOTOMETRY.

The photometric work of the bureau includes, besides research work in various lines, (1) maintaining the unit of candlepower which, at the proposal of the bureau, was accepted by the national laboratories of England and France, and is preserved through the medium of incandescent electric lamps; (2) the preparation and testing of electric lamps to be used as photometric standards; (3) the verification of gas lamps used as standards in the photometric measurements of gas; (4) the inspection and life testing of incandescent electric lamps purchased by the Government departments.

The adoption of the new candlepower unit of the bureau by both the gas and electrical industries has brought about uniformity in the photometric standards throughout the country.

Standard specifications for incandescent lamps issued by the bureau are recognized by all manufacturers and have brought about a uniformity in the rating of lamps which is very much to the advantage of both makers and users. These specifications are frequently revised after conference between representatives of the Government and of the manufacturers.

Investigations are now in progress to determine the constancy of incandescent electric lamps, the accuracy of photometric measurements, and the reliability of flame standards employed in the photometry of illuminating gas.

ELECTROLYSIS.

Since the advent of trolley systems a great amount of damage to gas and water pipes and other subsurface structures has been experienced, due to the presence of stray currents in the earth. Vast

sums are spent every year by gas, water, and railway companies and by municipalities in efforts to mitigate this evil. While a great deal of progress has been made in methods of minimizing trouble from this source, much remains to be done before remedial measures can be applied with the degree of certainty which modern engineering practice demands. Closely associated with electrolysis from stray currents is the phenomenon of autoelectrolysis or self-corrosion, due to the presence in the soil of foreign substances, such as coal, coke, cinders, etc., which give a difference of potential against iron, or to differences in the physical structure of the iron itself. Corrosion due to this cause is often difficult if not impossible to distinguish clearly from that due to stray currents.

During the last few years much attention has been called to the possibility of damage to reenforced concrete by stray currents, and considerable alarm has been aroused in some quarters lest reinforced concrete buildings, bridges, and similar structures be seriously injured in this way. Whether or not such grave danger actually exists, the possibility of such danger having been established, the problem becomes one of extreme importance, and a thorough study of the conditions under which the trouble may occur, as well as the best methods of preventing or minimizing the trouble, is imperative. Recognizing the importance of the subject, and acting in response to important engineering interests, the Bureau of Standards is engaged in a comprehensive investigation of this subject, involving all the different phases of the problem. This work has been in progress for more than a year past, and several papers representing the results of the work to date are now in preparation. It is planned to continue this work as circumstances may require.

HEAT AND THERMOMETRY.

The work of the bureau in connection with heat measurements is primarily the maintenance of a standard scale of temperature always available to the public for reference, and, secondarily, the making of tests and the investigation of problems of all sorts in which accuracy in the measurements of temperatures is essential or which for other reasons may advantageously be conducted in laboratories especially equipped for experimental work in heat.

The standard scale of temperature between 0° and 100° C. (32° and 212° F.) is represented by a series of standard mercurial thermometers, which agree to within 0°.002 C. with those which define the scale of the International Bureau of Weights and Measures. Above and below this range the scale is founded on a number of fixed base points reproducible by the boiling or freezing points of chemically pure substances. The value of these base points are expressed

in terms of the gas scale. Measurements of temperature are made by thermometers or pyrometers of various types standardized at these base points; and any thermometer or pyrometer sent in for test is standardized in terms of the scale of the bureau, by comparison with such instruments, or by test at the base points. Among the instruments so tested the following classes are of obvious importance: Clinical thermometers, of which some 15,000 are tested every year; calorimetric thermometers, used in determining fuel values, especially in connection with the award and settlement of coal contracts; mercurial thermometers, for use in controlling various technical operations conducted below red heat; pyrometers of many kinds—resistance, thermoelectric, optical, total radiation, etc.—which are used in a great variety of technical operations, e. g., in the glass, ceramic, and metallurgical industries, where high temperatures must be accurately controlled.

An important branch of work directly dependent on the possession of very exact means for measuring temperatures is that of determining the specific heats and heats of combustion of substances. This includes the heats of combustion of certain pure gases which enter into the composition of illuminating gas and certain materials capable of a high degree of purification, such as sucrose, naphthalene, and benzoic acid, which are distributed to outside fuel-testing laboratories for use in standardizing their own instruments.

The variety of miscellaneous tests on the thermal properties of materials requested from the bureau is very large, among the most important being tests of the melting points of fire brick and other refractory substances, and of the melting or transition points of alloys, in connection with which an elaborate investigation of the effect of heat treatment on the modern steels is under way.

Besides the work already noted, which has a direct connection with the improved conduct of technical operations in the great industries, various researches are in progress tending to the improvement of methods of precise measurement in the domain of heat or of our knowledge of important thermal constants. Among these investigations may be mentioned: Studies of freezing and boiling points for the further fixation of the standard scale of temperature; the development of accurate methods of calorimetry; the investigation, at high temperatures, of the laws of radiation on which the indications of optical and other radiation pyrometers depend, and of the emissive powers of various materials at which such pyrometers may be sighted; an investigation of some properties of the thermometric gases at ordinary and low temperatures; a comparison of various instruments for testing the viscosity of lubricating oils, etc.

OPTICS.

The work in optics consists chiefly in the determination of the optical properties of materials and optical constants, which includes radiometry, spectrometry, polarimetry, and interferometry. Such researches are valuable in supplementing other methods used for this purpose. Besides the researches mentioned, many optical tests are made for the Government and the general public, such as telescopic and photographic lenses, prisms, samples of glass, polariscopic apparatus, and sugar analyses.

In interferometry researches have been completed or are in progress on the use of spectrum lines and their application to the most refined methods of measurement of length.

The bureau has determined the purity and intensity of many sources of monochromatic light, the relation between the luminous intensity and energy intensity of radiation, the radiation of conducting helium gas as a primary light standard, the fidelity of photographic lenses as to reproduction, the luminous equivalent of radiation, and many other problems of a similar nature. An important investigation recently published relates to the luminous equivalent of radiation, a problem which underlies the theory of light measurement and the establishment of a rational absolute scale of luminous intensity. A method has also been developed for constructing a rational color scale and establishing primary standards of pure color. This is an important subject and one which has many industrial and technical applications.

The bureau in its radiometric work investigates various problems in light and heat emission, absorption, and reflection, particularly in the infra-red. It has studied the laws of radiation of various substances and also the instruments and methods used in such researches. An exact determination of the spectral reflecting power of metals has also been published.

Raw sugars that are imported are also tested to determine their purity, which it is necessary to know in order to fix the amount of the tariff duty. In this connection samples are sent in daily from the various customhouses for test. Exhaustive researches are also carried on to improve the methods and instruments used for testing at the ports of entry. The importance of applying the most accurate and scientific methods of polarimetry to the collection of the revenue on sugar and to industrial processes is increasing. For this purpose, among other things, pure sugar is indispensable. The problem of producing relatively large quantities of this material of unexcelled purity has been successfully solved by recrystallization in a vacuum. The demand on the bureau for samples of this sugar is rapidly growing, and many samples are now sent out for

scientific use. The distribution of such samples for standardization marks an important step in optical measurements and calorimetry.

CHEMISTRY.

Broadly speaking, the chemical work of the Bureau of Standards is of two kinds, routine and research, done independently or in cooperation with the various divisions of the bureau. By far the larger part of the routine work is on behalf of the Government—analyses of iron, steel, alloys, cement, rubber, oils, paints, varnishes, papers, inks, and similar miscellaneous materials. Most of this work is done for the Isthmian Canal Commission, the Office of the Supervising Architect of the Treasury, the Government Printing Office, and the General Supply Committee of the Government departments at Washington. As examples of research work on behalf of the Government may be mentioned investigations upon celluloid and articles made from it, with reference to their acceptance for transportation in passenger vessels of the United States; printing and record inks, with a view to improving their quality; the celluloses used in paper, the effect of age, sizing, etc., upon them; the preparation of the purest possible ethyl alcohol to serve as a basis for new density tables for mixtures of alcohol and water for use by the Internal Revenue and Customs Services.

TESTING MATERIALS.

An important branch of the bureau's work relates to the testing of materials. This was part of the work assigned to the bureau by act of Congress, March 3, 1901, by which the bureau was established. The development of the work was taken up as rapidly as funds were provided for it until it now includes a large variety of structural, engineering, and miscellaneous materials. The importance of official tests of materials by the Bureau of Standards arises from the fact that the bureau has the facilities for all kinds of physical measurements. Among the more important materials may be mentioned cements, concretes, steels, irons, bricks, clays, nonferrous metals, alloys, and rubbers for various purposes, leathers, papers, cloths, inks, paints, mucilages, twines, ropes, oils, and many others. In many cases satisfactory methods of test are not available, and researches are necessary to devise new methods. The routine tests of such materials are more or less directly concerned with every department and bureau in the Government service as well as the general public. Equally important with the testing is the study of the practical and scientific basis for specifications, the desirable qualities in materials, their accurate description in terms of physical and chemical properties which may be measured or tested by standard tests and analyses, standard methods of sampling, stand-

ard instruments and methods of testing, and finally the preparation of standard specifications for the guidance of the manufacturer and purchaser. This work should eventually result in the adoption of definite specifications and tests for all materials in use and thus furnish a scientific basis for manufacture and sale and a reliable and impersonal standard for inspection and acceptance.

CEMENT.

In connection with the testing of structural materials, the bureau is conducting several cement-testing laboratories in Washington, Pittsburgh, and elsewhere, where the cement used in the construction of public buildings in all parts of the United States is tested. The cement used in the construction of the Panama Canal is tested by the bureau in its branch laboratory at Northampton, Pa. The quantity inspected at this laboratory averages from 5,000 to 7,500 barrels per day.

In addition to the routine testing of cement various problems are being investigated, and studies are being made in an endeavor to improve the methods of testing. A small cement kiln has been installed at Pittsburgh for studying problems in connection with the manufacture of cement, varying the character of the raw materials used, temperature of burning, etc., and studying the effects of these variations in connection with physical tests. An exposure station has recently been established at Charleston, S. C., for continuing the investigation, started at Atlantic City, as to the effect of sea water on cements, mortars, and concretes. A number of technical papers giving the results of important investigations upon cement and concrete are now in press. The preparation of standard specifications for cement is now in progress under the auspices of the Bureau of Standards, to fix uniform tests and requirements for the United States.

PAPER.

Of vital importance to all users of paper is the bureau's investigation and testing of papers. As in other lines, testing and research are proceeding together. The bureau tests all the papers used in the publications and printing of the National Government. Experts now furnish the data necessary to eliminate undesirable papers, and quality is determined by scientific tests rather than by inspectors' judgment. As a result of the movement for more intelligent buying, print papers are bought on specifications and samples of all deliveries are analyzed and tested at the bureau. The bureau determines the fiber composition by the microscope, the folding endurance by the Schopper folder, the weight by special balances, the bursting strength on standard paper testers carefully calibrated in advance,

and the tensile strength and thickness by special devices. After several years of such work the ground is prepared for a thorough examination into the factors which affect the qualities of paper. The analyses of the bureau are such as to enable the expert to reproduce the formula by which the paper was made. The researches in progress include the effects of humidity upon the properties of paper, such as strength, weight, thickness; the deterioration of paper by coloring matter, loading, sizing, etc., and the study of the durability of wood cellulose as compared with cotton and linen. The bureau has installed a paper-making machine for producing experimental papers under predetermined conditions and of definite composition. This will enable the bureau to investigate the properties of paper by the rigorous control of the conditions of its production.

TEXTILES.

The bureau is engaged in the determination of the physical properties of textile materials from the raw fiber to the finished product. These tests include a wide range of measurement, such as the determination of the absorption of moisture by wool, cotton, silk, and jute fiber at different percentages of relative humidity; the shrinkages of raw wool; the temperatures to be applied to the different fibers to obtain constant or bone-dry weight; the textile strength of yarn and other fabric as affected by using different lengths of test pieces; the effect of moisture upon the length, strength, weight, durability, etc., of textiles. Textile raw materials are sold by weight, and the change of weight due to the absorption from the air is therefore a matter of commercial importance. Other vital problems in connection with textiles are in progress, in which the Government departments, the manufacturers, and dealers have expressed a keen interest.

MISCELLANEOUS MATERIALS.

Among the materials tested are cast iron, steel, and other metals, leather, mechanical rubber goods, asbestos sheet packing and other general supplies. The metals are tested for strength and to determine compliance with specifications, which vary according to the intended use of the material. Finished metal products, such as tools, saw blades, etc., are tested under working conditions, the tests varying with the uses, frequently involving special investigations.

Leather is inspected for quality and tested for strength, stretch, absorption, and weight, to determine its adaptability for special usage, such as belting, belt lacing, harness, shoes, and other products. Rubber, in the form of mechanical rubber goods, such as sheet packing, valves, water hose, air hose, steam hose, suction hose, dredging sleeves, rubber belting, etc., is tested for strength, elasticity, and gen-

eral quality, as indicated by its behavior under working conditions, as well as certain special tests which have been developed for such materials.

Much of this work has been done for the Isthmian Canal Commission and the various Government departments, with the result that after a number of rejections on account of failure to comply with specifications it is now found that such materials purchased on contract are of much better and more uniform quality than it was possible to obtain before the custom of testing had been introduced. The saving in expense is at the same time appreciable.

Special investigations are now being carried on to determine the physical properties of various rubber compounds which are used in the manufacture of mechanical rubber goods, with a view to developing standard specifications for such materials as hose, packing, etc. Similar work is being done in the case of leather belting.

ENGINEERING INSTRUMENTS.

A large class of measuring instruments are used in the various branches of engineering. The investigation and testing of such instruments is an important part of the bureau's work, comprising, among others, water-current meters, anemometers, speedometers, taximeters, tachometers, pressure gauges, water meters, gas meters, steam-engine indicators. These instruments are tested for accuracy, and certificates issued showing corrections where desired.

ENGINEERING TESTING.

The work of testing materials requires a large variety of testing instruments and other equipment. Among these may be mentioned the 2,300,000-pound Emery testing machine for load of tension and compression to accommodate specimens up to 30 feet in length. At its Pittsburgh laboratory the bureau is erecting a 10,000,000-pound Olsen testing machine. A number of other machines of smaller capacity are available for lower ranges. As an example of research with such testing machines may be mentioned the investigation in conjunction with the American Society of Civil Engineers of the strength of a series of steel columns which will be tested to correct and confirm the formulas used by engineers for computing column strength—formulas upon which the efficiency and safety of building construction depend.

The bureau is engaged in the test of structures in which strain measurements are taken of deformation under dead loads. This class of work includes civil engineering and architectural structures, embracing bridges, buildings, railway tracks, steam boilers, and pavements. Strain measurements are carried on in conjunction with

laboratory tests of the physical properties of the different materials represented in engineering structures. This embraces close observations on the behavior of the materials in service, supplementary to but beyond the scope of testing machinery. The value of this work lies in the fact that it is directly applicable to service conditions and is made upon material as actually used in finished structures and subject to working conditions.

This work is the summation of all testing, inasmuch as it embraces all the factors present in materials in structures. The work has included measurement during construction on some of the tallest buildings in New York City.

PUBLICATIONS.

An important function of the bureau is the distribution of information. This is done through personal visits of the people who desire special information, such as manufacturers, technical experts, and others who wish to consult the scientific officers of the bureau regarding their work and to inspect the bureau's plant and equipment. Such information is also largely accomplished by means of correspondence, which is steadily increasing in volume. Finally the most important medium of distribution of information concerning the bureau and its work is through its publications. The Bulletin of the Bureau of Standards embodies the results of the scientific work of the bureau in reference to standards, instruments, methods of measurement, and physical constants. The bulletin contains the collected papers, of which about one volume is issued each year. The Circular of the Bureau of Standards contains information upon scientific subjects, including methods of testing, the properties of materials, legislation concerning weights and measures, regulations, specifications, and other information of general interest. The Technologic Papers of the Bureau of Standards cover the more strictly technologic work of the bureau. The separate scientific papers are issued in the form of reprints for general distribution upon request. In addition to the above, the bureau also issues miscellaneous publications, including the descriptive pamphlet of the metric system, tables of equivalents, reports of weights and measures conferences, and similar material.

EQUIPMENT.

Besides an extensive modern equipment of scientific instruments and apparatus for experimental and testing work, the general equipment of the bureau is in many respects unique, since the range of scientific work embraces so wide a variety of needs. In temperature work ranges must be available from that of liquid air to the heat of the electric arc; in electrical work all varieties and the maximum ranges of current practicable are used; in chemical work the usual

facilities are supplemented by many special services. For all divisions of the work are available, as required, electrical power, refrigeration, steam, gas, compressed air, vacuum, hot, cold, iced, and distilled water, liquid air, cold brine, etc. In certain classes of work temperature control is required. In others control of the humidity is needed, e. g., the water is frozen from the air reducing the humidity to the desired point, while in others the humidity is varied at will. Similarly other conditions are controlled to secure the best conditions for effective work.

The bureau has a technical library of more than 8,000 bound volumes—chiefly on physics, chemistry, and technology—and regularly receives 270 journals and proceedings of scientific and technical societies. Access to the literature in any subject is desirable for effective work, especially in technical investigations.

The character and quantity of the results attained by the bureau have largely depended upon the facilities available for constructing special apparatus for its investigation and testing. In almost every field new and improved apparatus must be designed and constructed. The bureau is therefore provided with a well-equipped instrument shop, skilled mechanicians, and modern machinery, which have been an important factor in the maintenance of a high standard in its technical work.

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